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Voice-driven fleet management system for agricultural operations

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ABSTRACT

Food consumption is constantly increasing at global scale. In this light, agricultural production also needs to increase in order to satisfy the relevant demand for agricultural products. However, due to by environmental and biological factors (e.g. soil compaction) the weight and size of the machinery cannot be further physically optimized. Thus, only marginal improvements are possible to increase equipment effectiveness. On the contrary, late technological advances in ICT provide the ground for significant improvements in agri-production efficiency. In this work, the V-Agrifleet tool is presented and demonstrated. V-Agrifleet is developed to provide a "hands-free" interface for information exchange and an "Olympic view" to all coordinated users, giving them the ability for decentralized decision-making. The proposed tool can be used by the end-users (e.g. farmers, contractors, farm associations, agri-products storage and processing facilities, etc.) order to optimize task and time management. The visualized documentation of the fleet performance provides valuable information for the evaluation management level giving the opportunity for improvements in the planning of next operations. Its vendor-independent architecture, voice-driven interaction, context awareness functionalities and operation planning support constitute V-Agrifleet application a highly innovative agricultural machinery operational aiding system.
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1. Introduction

Agricultural production needs to deal with a continuous increase in productivity to meet the increased demands for agricultural products [1]. Until now, these demands mostly triggered the physical optimization for improving agricultural equipment efficiency and productivity, which resulted in larger and more productive machinery. However, due to biological and environmental factors –e.g. soil compaction [2,3]– the weight and size of the machinery cannot be further physically optimized [4,5]. In this light, only marginal improvements to the effectiveness of modern agricultural machinery are possible [6]. On the contrary, late technological advances in Information and Communication Technologies (ICT) provide the

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ground for significant improvements in agri-production efficiency [7,8]. In brief, ICT provides the opportunity to farmers, even smallholders, to access data and the technical information they require to increase yields [9], while reducing the geographical handicaps around the globe [10]. Especially in the case of complex operational systems (e.g. in harvesting operations where multiple-machines cooperation is required), there is a large potential related to optimizing the interaction between machines instead of simply increasing the size and productivity of the individual machines [11,12]. In this context, ICT-based tools can effectively support the management of field operations and assist in the agricultural production organization [13,14]. A report published by the World Bank explicitly details the influences of ICT in agriculture [9].

The complexity of agricultural field operation processes requires capturing and inclusion of all logistical and economic linkages into a system approach so as to improve efficiencies and reduce operational cost [15–17]. Towards this concept, several agricultural fleet management products have been launched in the market. However, this market is extremely fragmentary since the majority of such products are not compatible for different machinery brand names [18]. Moreover, the already developed tools have a centralized architecture. In this context, they provide information to a central decision-maker, without allowing any local machine-to-machine (i.e. operator-to-operator) information exchange. Another drawback of already developed solutions is that crucial information regarding operational status of a machine (e.g. completion of a task) requires the manual interaction of the operator with the tool's interface. It is evident that non-automatically generated information has a significant impact in time and user's concentration on other parallel tasks in the field.

In industry, Fleet Management Systems are widely used for a number of years [19–22]. Presently, such systems have advanced into providing enterprises with integrated management tools that connect all different parts of the business. In the agriculture domain, there is an ongoing trend where more sophisticated equipment are being designed, which also exploit the potential of advanced ICT technologies [23–28]. The challenges facing the agri-fleet management and relative industries are numerous and complex (e.g. time management, monitoring of efficiency etc.) [29]. In order to address such challenges, a high level of cooperation and coordination is required to exploit available resources more efficiently. More specifically top challenges identified by industrial stakeholders include fleet cost-reduction, fuel price volatility, increased fleet safety, reduced accident rates, environmental performance of agri-fleet, and increased productivity of both human and machinery capital. However, despite its criticality, the high cost of such systems, the centralized management orientation, and the required manual efforts by the users in order to receive and provide real time information, has detained a wide penetration of fleet management systems in the agri-business sector.

In this paper, the development of a fleet management system application, namely the V-Agrifleet application, for material handling agricultural operations is presented and demonstrated. V-Agrifleet has been developed to provide a "hands-free" interface for information exchange and an "Olympic view" (overall view) to all coordinated users. The tool gives end-users the ability for decentralized decision-making. More specifically, V-Agrifleet has been designed to be used by various types of end users (namely farmers, contractors, farm associations, agri-products storage and processing facilities) in the framework of optimizing tasks and time management. At present, V-Agrifleet is characterized as a product at Technology Readiness Level (TRL) 6, since the technology is currently demonstrated in relevant environment while not yet demonstrated in operational environment that would further advance the prototype to TRL 7.

The work herein presented is divided into five sections. Section 2 presents the conceptual approach and the technical implementation aspects of the V-Agrifleet application. Section 3 presents the test-cases that were performed in order to demonstrate the tool's applicability and summarizes the main results from its implementation. In Section 4 managerial and usability insights following the test-cases are discussed in order to better understand the added value of the tool. Section 5 contains the main conclusions of the paper.

2. V-Agrifleet design and development

2.1. *Brief description of the application*

The V-Agrifleet application is a decentralized agricultural fleet management tool for sharing information among the fleet units. V-Agrifleet is an Android application, developed for mobile phones and tablets. The tool incorporates voice-driven functionalities and provides information sharing between all machine-to-machine pairs of the fleet. For instance, in a harvesting operation, the operator of the harvester is able to locate in the map the position of a selected transport unit and its operational status, i.e. whether travelling to the depot or to a field, if it is carrying load or not, if a malfunction has been occurred, etc. Apart from locating transport trucks and agricultural machinery, the application provides a holistic picture of the operational status of all involved primary (e.g. harvesters) and transport units. During discrete events of the operation (e.g. loading completed, harvesting in a field completed, etc.), each operator provides (by formalized voice commands) real-time information which is shared among all authorized users. In this context, with the use of the V-AgriFleet app, fleet is context aware of the activity of each unit and thus adapts the configuration according to their detected statuses by giving them the ability for decentralized decision-making.

2.2. *Users requirements*

The first step towards the development of the V-AgriFleet application is the definition of the user requirements for all identified target user groups (farmers, contractors, and operators). The determination of the end-users' needs was based on personal, semi-structured interviews that were carried out in June 2015. To avoid bias during the interviews, standardized answers were introduced. The identification of the user needs followed the process illustrated in Fig. 1. The list of the user requirements was adopted from [18]. The require-

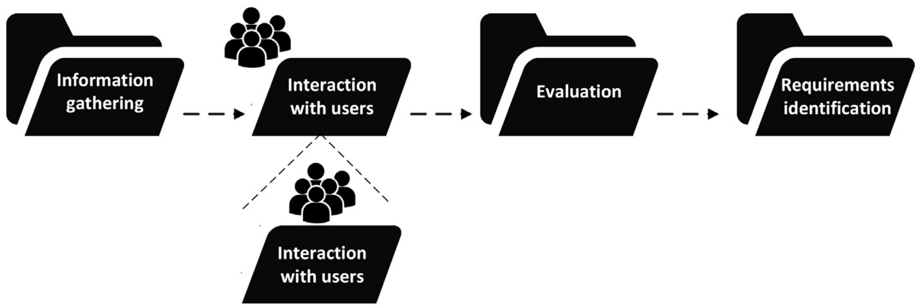

Fig. 1 – Identification of user needs.

ments which derived from the machinery contractors, embrace a fleet management solution that fulfils the information need for the operation's control. The focus was mainly on transport control, technical and operational data acquisition and route guidance (e.g. between fields and storage facilities). The voiced requirements from operators concentrated mostly on functionalities within the farm, namely online monitoring, scheduling of operations, on-farm route guidance, etc. Real-time positioning and vehicle tracking features were defined as core requirements for the V-AgriFleet application.

2.3. *Application design*

To determine the functional specifications of the V-AgriFleet application, the Quality Function Deployment (QFD) methodology was implemented [30]. The primary goal of the QFD methodology is the translation of end-user requirements into specific technical requirements [31,32]. The latter considers all different stages of product design and assists the transformation of end-user needs into technical characteristics of a product or a service [33,34]. The following steps have been considered during the process; (i) Customer identification, (ii) Customer requirements, (iii) Prioritization of customer requirements, (iv) Identification of design parameters, (v) Determination of relationships and (vi) Correlation between the design parameters.

Based on the above methodology, the V-AgriFleet application was designed with a typical three-tier architecture (Fig. 2). First, harvesting, geospatial and logistics data are collected by the sensors (GPS receivers and voice commands receivers) placed in the fleet units. Harvesting data refers to the operational status (state) of the harvester(s), e.g. "temporary hopper is full", "starting operation in Field 3", etc. Logistics (Transport) data refers to the information on the transportation tasks, e.g. in the case of a transport unit "travelling to Field 2", or "servicing Harvester 1". Geospatial data refers to the navigational data on the exact locations and the speeds of the fleet units. In the second tier, all the above information is integrated in a real-time manner into a central repository in order to support the context awareness and decision-making processes, e.g. routing and next tasks to be allocated to the units. In the third tier, the users can have access through their mobile devices to the provisioned orders (task allocation) and navigational data for routing (step-by-step directions), as well as the operational status of the other units of the field.

The components' interaction is presented in Fig. 3. In brief, the V-AgriFleet application consists of the following modules; (a) Mobile Android application that collects, sends and requests operations data, (b) Identity Management for authenticating and providing access tokens to users, (c) Authorization PDP for authorizing the users, (d) PEP Proxy for intercepting and validating every request send from the android application, and (e) Context Broker for storing, providing and managing operations data.

V-AgriFleet exploits a number of FIWARE enablers in combination with the android technology. Firstly, an administrator creates other users (primary and transport units) in KeyRock (Identity Management GE) using RESTfull api and the admin port of the enabler. The administrator defines the roles and permissions for each user, while he/she is responsible for defining the coordinates of the fields and depots. As a next step, each user can communicate with KeyRock using the OAuth 2.0 protocol to receive an access token. With this token, the user may access Orion (Context Broker GE) through Wilma (PEP Proxy GE). Wilma enabler is the one that intercepts all communication to Orion and is responsible for two functions; (i) to determine whether the request is from a certified user, by sending the token to KeyRock, and (ii) to check whether the user has the right of access to what he asks for, contacting AuthZForce (Authorization PDP GE). Only for the cases where both aforementioned actions succeed, Wilma forwards the request to Orion. The latter hosts the repository where location data and status of agricultural machinery is stored. Through the android application, all operators, as well as the administrator, are able to continuously monitor the location of each unit, along with their status (Harvest, Travel, Block, Service etc.). Moreover, they can also communicate with each other, if required.

The application supports six different types of users, including Administrator-Supervisor (AS), Administrator and primary unit operator (AOP), Administrator and transport unit operator (AOT), Supervisor (S), Primary unit operator (OP) and Transport unit operator (OT). Their hierarchy is described in Fig. 4. For supporting the six types of users, four interfaces have been defined, namely Administrator, Supervisor, PU operator and TU operator. These interfaces are modular in order to cover the above-mentioned types of users. For exam-

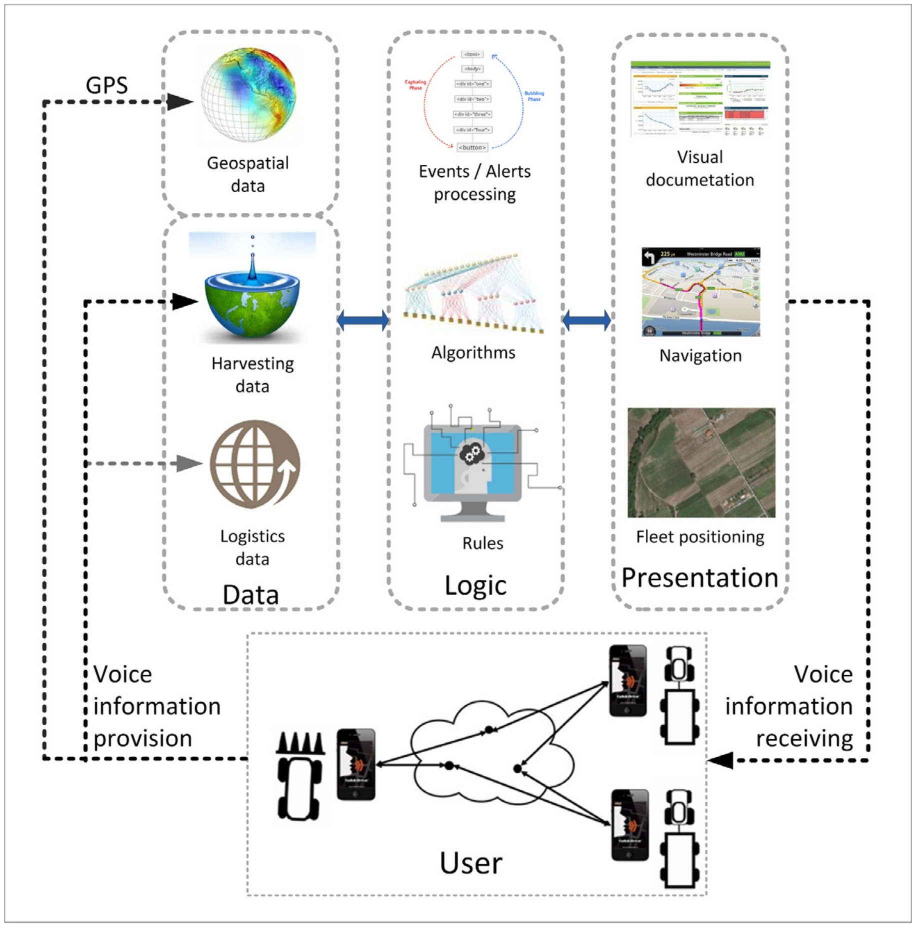

Fig. 2 – V-AgriFleet system architecture.

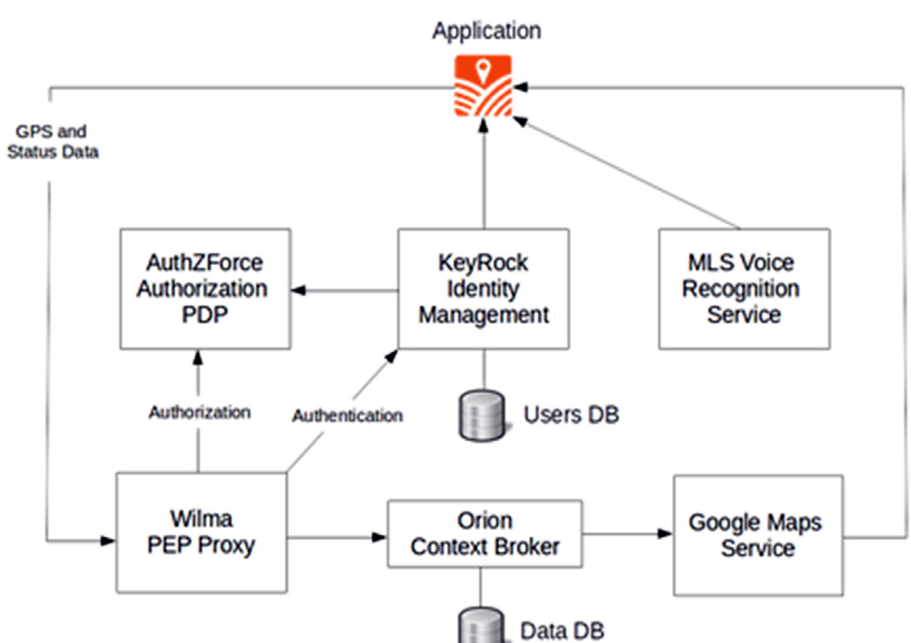

Fig. 3 – V-AgriFleet components' interaction with incorporated FIWARE enablers.

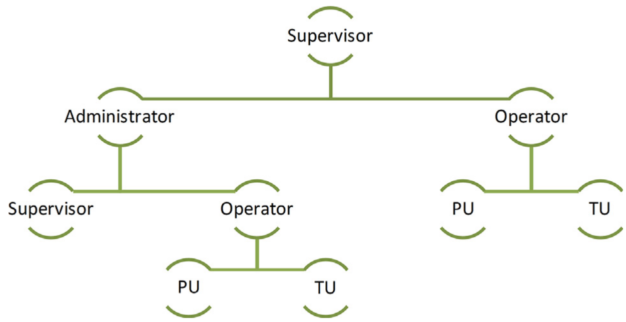

Fig. 4 – Different users' types (PU: primary unit; TU: Transport unit).

ple, in the case of a user who is the administrator and PU operator, the two corresponding interfaces are combined.

The general structure of the interface dedicated to the administrator is presented as an example in Fig. 5. From the interface, the administrator registers all authorized users before the operation commences. In the "user management" screen, all entries are repetitively inserted by texting. The only exception related to user management is the "use type", where the application provides the list of the various user types available. In the "location management", the user defines the tangible assets of the operation. For the insertion of the coordinates, the user is driven on the map where one can determine the location. The "map" button drives the user in the operational map where he/she can use the application's available orders, namely "Show", "Navigate", "Inform" and "Call". Similar interfaces are designed for the other types of users. Indicative GUIs of the V-AgriFleet application are depicted in Fig. 6.

3. Test-cases

3.1. Simulation test-case

Three test cases were designed and executed in order to demonstrate and verify the functions of V-Agrifleet application. Samsung Galaxy S7 Edge, Galaxy 3, and Huawei B199 smartphones were used for the test cases. The first "simulation" test was realized in order to verify that all application's components operate and interact properly with all incorporated FIWARE enablers. Specifically, the following components were tested and validated during the initial test case; (a) functionality testing, where the V-Agrifleet app was validated for functioning accurately, quickly and consistently, and (b) user interface and usability testing, where the V-Agrifleet app was validated for the quality of the front-end experience provided to its users. For the latter, visual and textual elements were considered in order to ensure that those are displayed correctly and efficiently. During the test case, navigation of all links to and from home screen point to the right destination screens was confirmed. Moreover, to ensure that the application displays correctly in different smartphones and tablets (of different screen sizes), the layout of the V-Agrifleet app was also checked and front-end performance, e.g. page render speed, image and script load times, etc. were validated.

The simulation test verified; (a) the proper input-output configuration of all selected FIWARE enablers, (b) the recognition of the defined voice "vocabulary" under a less than 5% error and the recognition of the selected synonym voice entries, and (c) the proper function of the main application, excluding the voice-driven functionalities, which had not been yet installed in the app at the time of the test-case.

3.2. Virtual test-case

As a next step, a "virtual" test case was realized. The aim of this second test case was to validate the usability of the V-Agrifleet application in real-world environment. As a prerequisite, the "virtual operators" were required to be fully aware on the use of the application, and thus, were accordingly trained before testing the application. The test case took place in an urban road network that is well-charted in the Google-maps and that simulated the "virtual operating environment". In brief, the following issues were tested and validated; (a) efficiency of communications between all different users within a fleet, (b) performance of operational status functionality, (c) correct localization of users, and (d) efficient navigation to any users, fields or depots. The "virtual" test case verified that; (a) all users of the application can monitor all other users in a running operation and that communications between all users within a fleet is properly realized, (b) any user is able to report his/her operating status

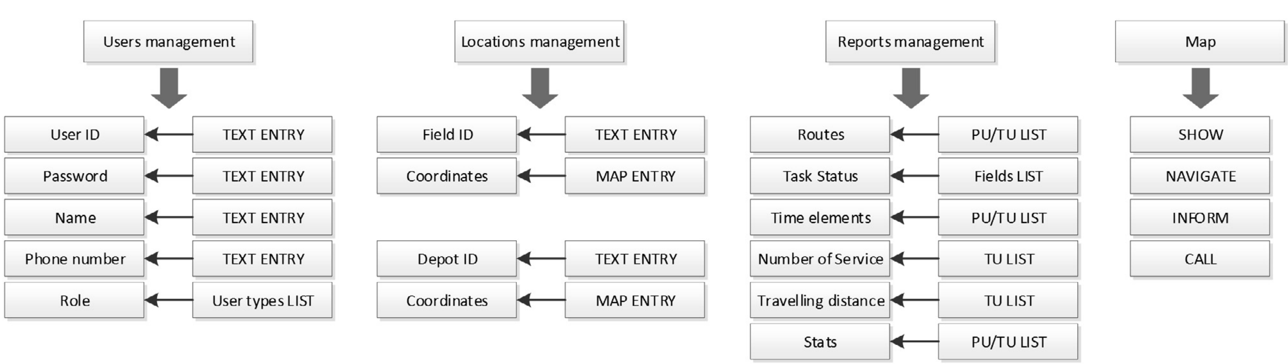

Fig. 5 – Administrator interface functional structure.

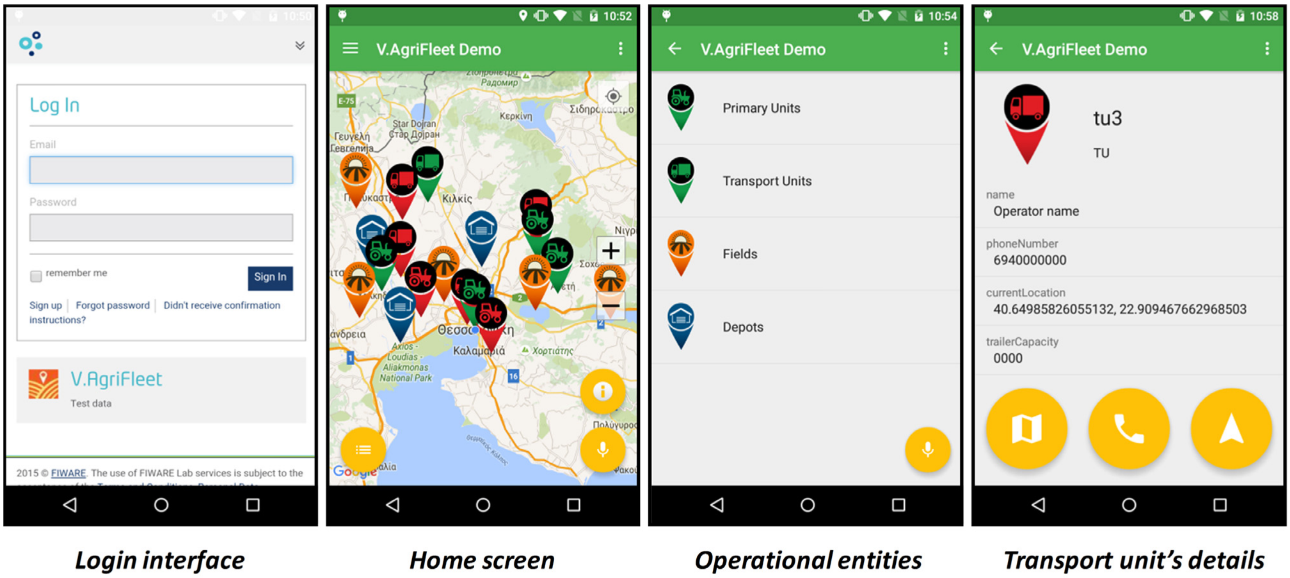

Fig. 6 – Screenshots of the V-AgriFleet application.

either via the mobile device screen or via voice reporting, and to view the operating status of the others (also via navigating in mobile device interface or by voice orders), and (c) any user can localize and is able to navigate efficiently to any of the other users (primary or transport units), fields or depots.

3.3. *Pilot test-case*

The third and last test case was the "pilot" test for the validation of the application on its use in large scale harvesting operations. This test case was realized in the Region of Thessaly, Greece. A large-scale operation was performed including four harvesters and six transport units in geographically dispersed fields (Fig. 7). During this test case, the transport units' navigation in unknown rural roads was validated. The system effectively provided the information necessary for transport units' assignment to the primary units involved.

4. Managerial insights

According to the authors' knowledge, the innovative aspects of the V-Agrifleet application (e.g. voice-driven interaction,

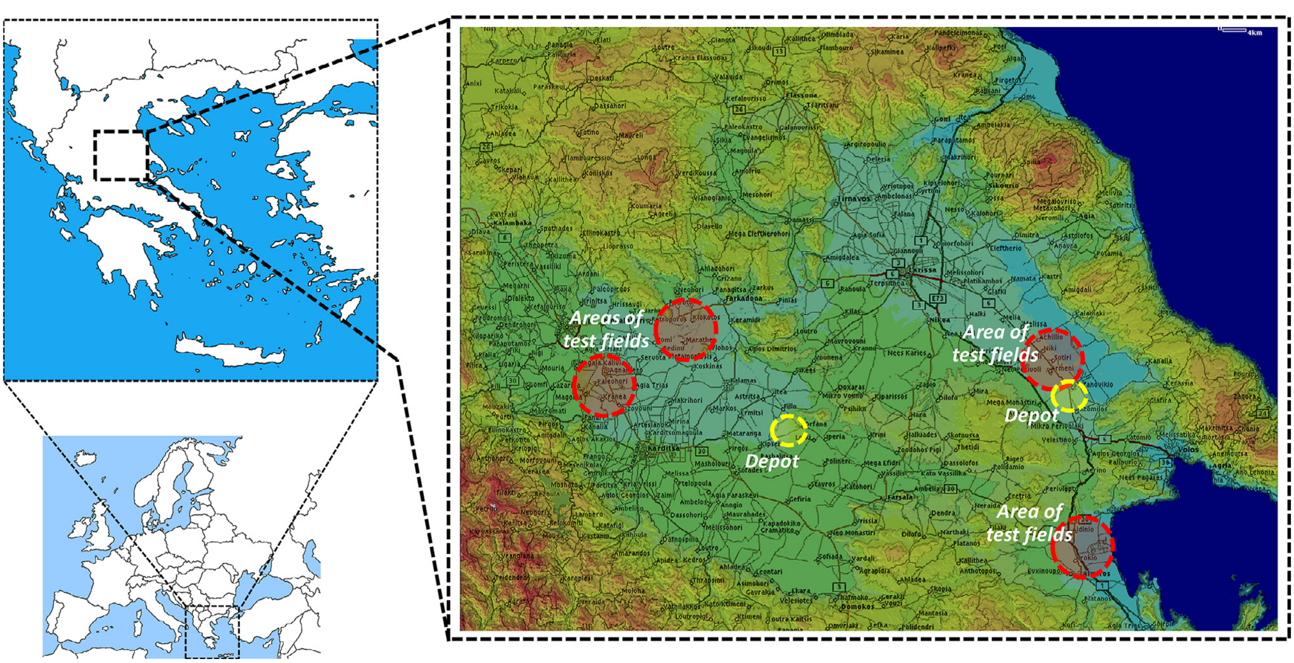

Fig. 7 – Area of pilot test case.

context awareness, operation planning) have never been introduced before in an agricultural machinery operational aiding system. In this context, the application's impact in the industry is expected to be significant and the product will offer exponentially expanding opportunities to its users. As a smart, decentralized, connected product, the V-AgriFleet application is expected to bring to the market new innovative functionalities, far greater equipment utilization and reliability, and cross-cutting capabilities that may transcend traditional product boundaries. With the use of the application, decision-making process within agri-business will decentralize, driving entrepreneurship to re-think, re-evaluate, and re-tool day-to-day operations, while incorporating ICT as an integral part of the agricultural production. The interconnection between all involved primary units, transportation units, depots and farm managers and the context aware fleet operation that the V-Agrifleet offers, is expected to improve the fleet's efficiency and economic performance. Apart from the economic benefits, the optimized fleet scheduling is expected to also result into reduction of the emissions, due to less fuel consumption, and thus improved environmental performance of the fleet.

The V-Agrifleet application's technology is directed to a rapidly growing market by offering a competitive and environmentally friendly solution for agricultural fleet management. Its central functional feature (voice-driven, context awareness, automated decision-making) that are missing from any relative existing application, secure a fast development and commercial take-up. The use of the application is highly expected to generate significant economic benefits for the end-users. More specifically, the economic benefits rely on cost reductions via time and trips saves and better decentralized coordination of field works. Based on the results from the field tests, the use of the application for the multiple-machinery coordination provides savings in the range of 8–10% of input time and 5–10% in the productivity of harvesting operations. Furthermore, the visualized documentation of the fleet performance may provide valuable information for the evaluation management level giving the opportunity for improvements in the planning of next operations and specifically in the tactical level, e.g. decision related to the number of necessary working units in a specific operation. It should be highlighted that as a cross-vendor solution, the application can be used without problems by farmers with new or existing machinery. Apart from the economic benefits, the application can also decrease the environmental impacts. Due to the significantly reduced bottleneck times, the context awareness of the operators and the optimized routing, significant reductions in the agricultural machinery's CO_2 emissions can be achieved.

5. Conclusions

V-AgriFleet is an innovative, prototyped and ready-to-market, agricultural fleet management application with minimal requirements for users' intervention in terms of human-application interface due to its voice-driven info exchange module. The application supports decision-making by providing critical information regarding the operation planning. The vendor-independent architecture, the voice-driven interaction, the context awareness functionalities and the operation planning support that V-Agrifleet application offers, constitute a highly innovative agricultural machinery operational aiding system.

Despite limitations, a decentralized fleet management tool which; (a) equally shares information between the units within a fleet, (b) operates in heterogeneous fleets independently of the machines' brand names and specifications, and (c) disengages operators from the manually interaction with the system by giving him/her the ability for a complete communication with the system by his/her own voice (for both giving or requesting information), substantially improves productivity and efficiency of agricultural machinery. Such a tool is anticipated to significantly reduce bottleneck times and thus, increase the productivity of agricultural machinery contractors and farmers who are cultivating cereals, industrial crops, or forage crops. The economic benefits for the users rely on cost reductions via time and trips saves, while also from better decentralized coordination of field works. Moreover, the voice-driven functionalities aid users by saving time in the tactical level (decisions related to the number of necessary working units in a specific operation) beyond the operational level.

Although very promising, the benefits of the developed application need to be thoroughly considered in the prism of the study's limitations. Clearly, the use of the application can bring significant added value to the end users. However, potential barriers for the application's market penetration (e.g. users' acceptability, price and competition) need to be thoroughly assessed before the V-AgriFleet application stands at TRL 9. Moreover, technical improvements in the interface and improvements in the human-machine interaction present a future challenge for the authors.

Conflict of interest

The authors declared that there is no conflict of interest.

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